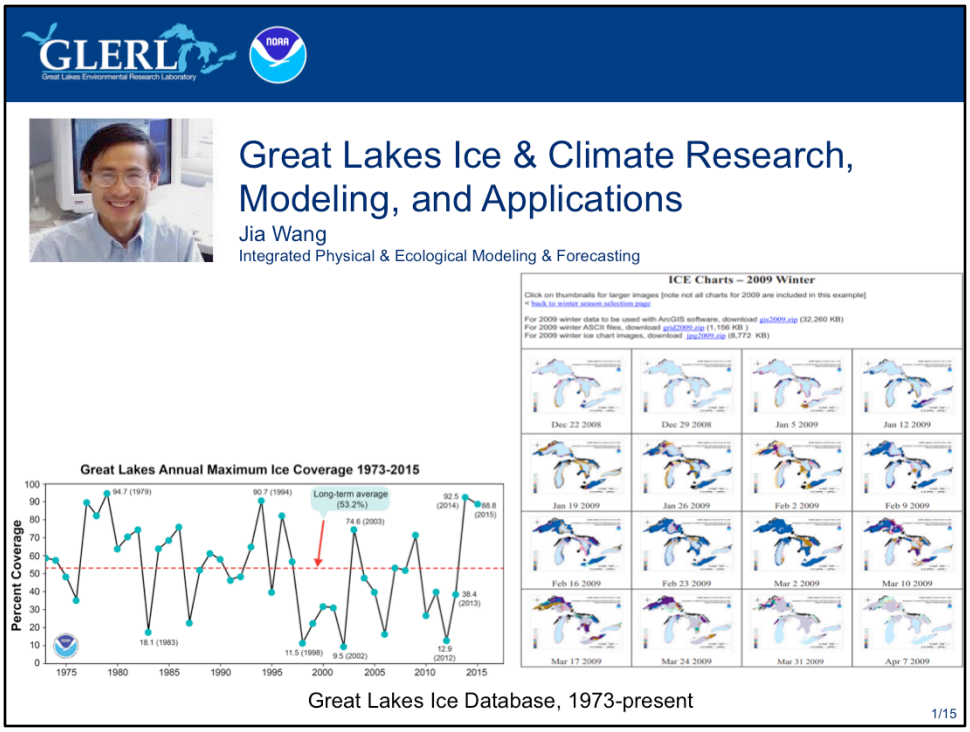
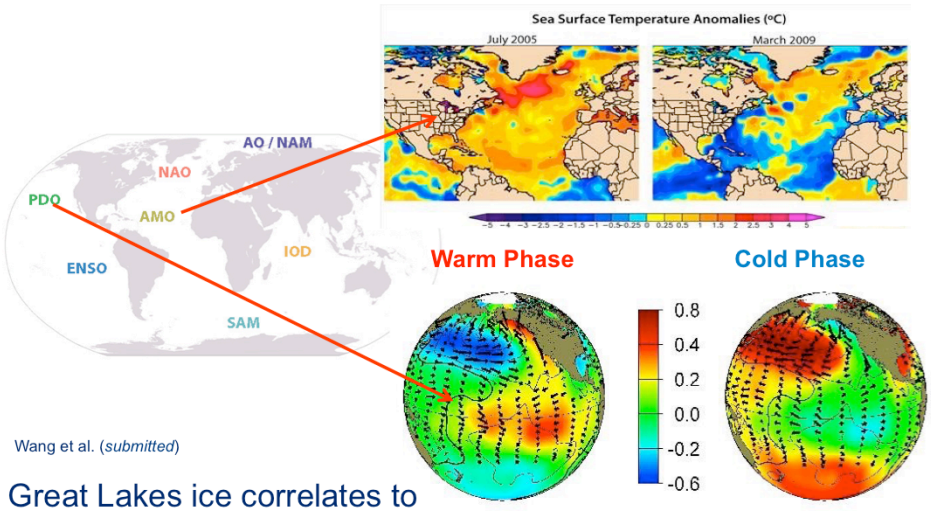


Outline:
1 - Seasonal forecasting of lake ice using indices of climate teleconnections that was transferred to medium-range lake ice projection
2 - Development of Great Lakes Ice-circulation Model (GLIM) that was transferred to short-term ice forecasting in GLCFS
3 - Development of five-lake FVCOMice model for research and forecast
4 - Arctic climate: Arctic Dipole Anomaly (DA) and Arctic Oscillation (AO)
5 - Coupled Ice-Ocean Model (CIOM) and coupled (ice-ocean) Physical-Ecosystem Model (PhEcoM) in the Bering-Beaufort-Chukchi Seas and the Arctic Ocean
6 - Summary and future efforts

This work aligns to the following NOAA goals:
Science: Climate Adaptation and Mitigation
Improved scientific understanding of the changing climate system and its impacts
Assessments of current and future states of the climate system that identify potential impacts and inform science, service, and stewardship decisions
Mitigation and adaptation efforts supported by sustained, reliable, and timely climate services
A climate-literate public that understands its vulnerabilities to a changing climate and makes informed decisions
Science: Weather-Ready Nation
Improve freshwater resource management
Improve transportation efficiency and safety
A more productive and efficient economy through information relevant to key sectors of the U.S. economy
Science: Healthy Oceans
Improved understanding of ecosystems to inform resource management decisions
Science: Resilient Coastal Communities and Economies
Resilient coastal communities that can adapt to the impacts of hazards and climate change
Comprehensive ocean and coastal planning and management
Safe, efficient and environmentally sound marine transportation
Safe, environmentally sound Arctic access and resource management
Education: Science-Informed Society
Youth and adults from all backgrounds improve their understanding of NOAA-related sciences by participating in education and outreach opportunities

1) R&D: Major global-scale atmospheric teleconnection patterns



Wang et al. (*submitted*)

Great Lakes ice correlates to AMO (linear: r=-0.31) and PDO (non-linear: r=0.19)

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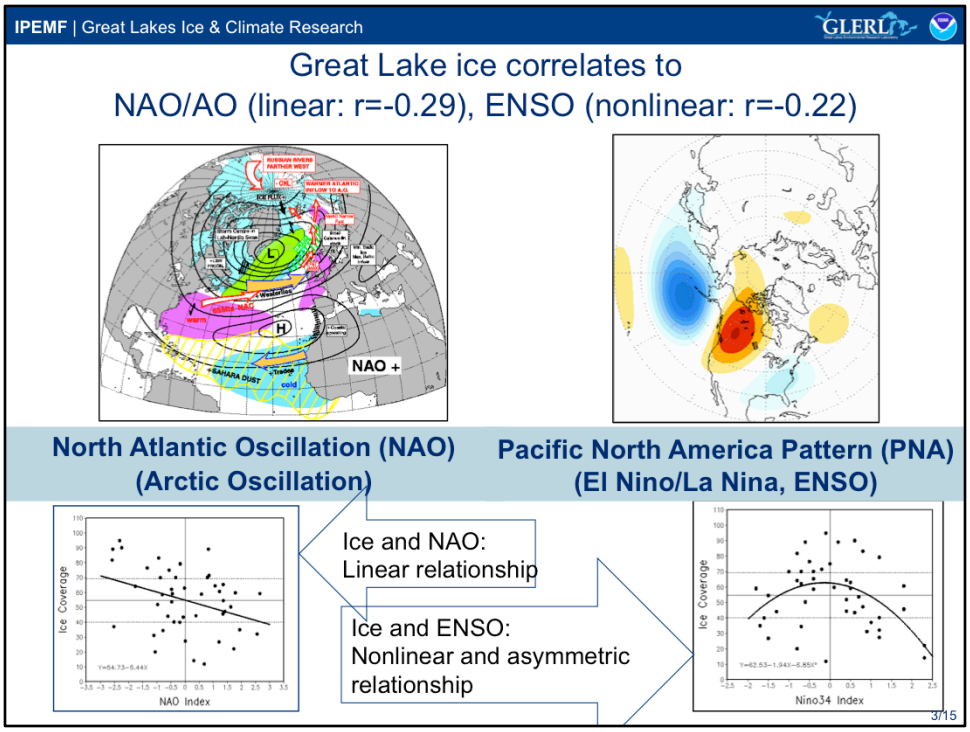
AMO – Atlantic Multidecadal Oscillation
PDO – Pacific Decadal Oscillation

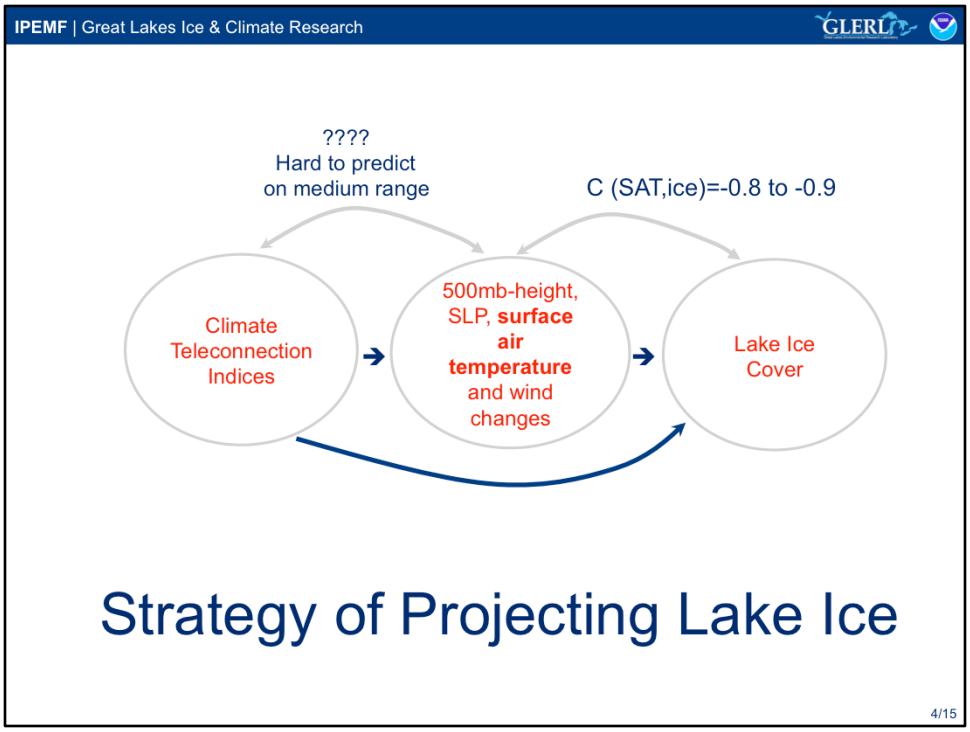


The Great Lakes are not the action center – we are on the periphery of the action center.

ENSO – El Nino and Southern Oscillation
NAO – North Atlantic Oscillation

Bai et al. (2012, JGR);
Wang et al. EOS, 2010
Wang et al., 2010 EOS; 2012 JC; Bai et al. 2011 JAMC, 2012, JGR; Wang et al. submitted

(Joint efforts by GLERL and CILER)



If we go from Climate Teleconnection Indices to 500mb-height, SLP, **surface air temperature** and wind changes to Lake Ice cover we add room for error and large uncertainty. If we skip from teleconnection indices to Lake Ice cover we remove a large margin of error.

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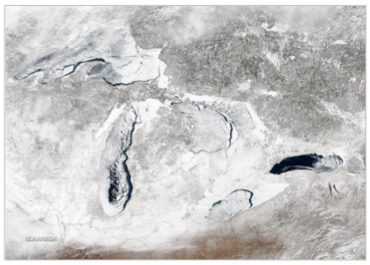
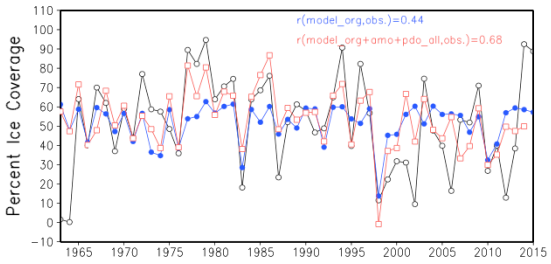
R2A: Medium-range projection of lake ice using climate indices of NAO, Nino3.4, AMO, and PDO

(GLERL led the efforts with CILER, NIC, academia, LimnoTech)



MODIS 03/06/2014

Hindcast



R2A: Seasonal prediction model:

Blue – old model (Using NAO and ENSO only), r=0.44

Red – new model (Using NAO, ENSO, and AMO, PDO) r=0.68

Using the models, GLERL has provided a seasonal ice outlook since 2010:

This winter—Annual Maximum Ice Coverage (AMIC) was projected to be 31% in November 2015; On 2/14/2016, AMIC was 34% (average is 53%)

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(Bai et al. 2012 JGR; Wang et al. submitted)

R2A: Seasonal prediction model:

Y=0.45 -0.13xNino34 -0.4xNino34**2 -0.4xNAO+ 0.21xNAO*Nino34**2 (ENSO&NAO on intera.)

-0.5xAMO+0.15xPDO+0.05xPDO**2 (AMO&PDO linear and squared on decadal)

+0.01xAMO*NAO-0.08xPDO**2xNino34**2 (crossing decadal and interannual interactions)

+0.16xPDO**2xAMO (AMO&PDO interactions on decadal time scales)

R=0.68, R**2=0.46 (Best)

Red – new model

Blue – old model

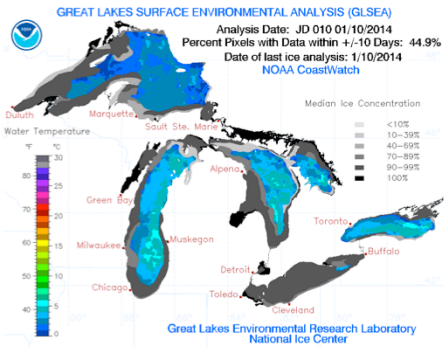
AMIC – Annual maximum ice cover

2) R&D: Development of Great Lakes Ice-circulation Model (GLIM): Satellite and in situ data used to validate GLIM

(Joint efforts by GLERL and CILER)

R2O: GLIM 5-day Prediction during 2013-14 (heavy) ice season

Prediction skill has been improved from 2012 to 2014 by nudging daily ice concentration from National Ice Center.



Wang et al. (2010). *JGLR*.

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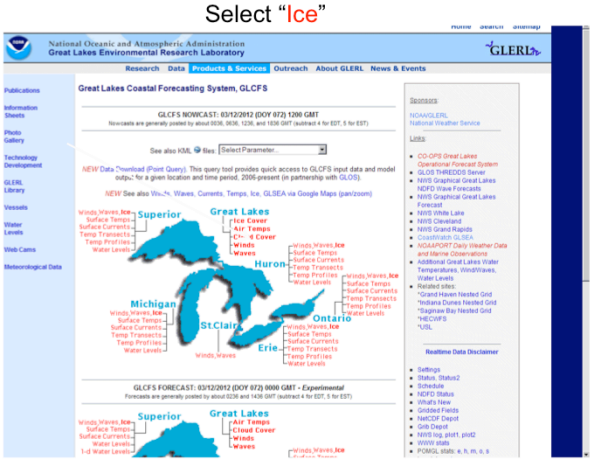
GLIM – Great Lakes Ice-circulation Model

Quality of prediction – 5-day prediction using data assimilation

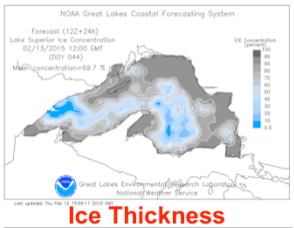
R2O: GLERL Ice Forecast (GLIM) has been incorporated into the GLCFS since 2010

http://www.glerl.noaa.gov/res/glcfs/

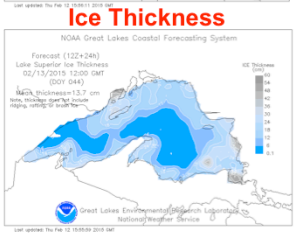
Select "Ice"



5-day Forecast Ice Concentration



Ice Thickness



Wang et al. (2010). *JGLR*; Fujisaki et al. (2012). *JGLR*; Fujisaki et al. (2013). *JGR*.

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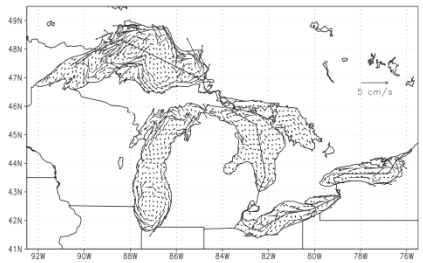
3) R&D: Development of 5-lake unstructured-grid FVCOM with ice

Grids

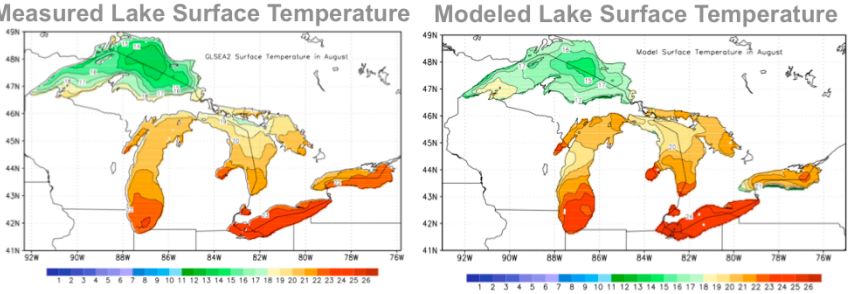
Modeled summer circulation



Measured Lake Surface Temperature

Modeled Lake Surface Temperature

Aug



Bai et al. (2013). *Ocean Modelling*; Luo et al. (2012). *JGR*)

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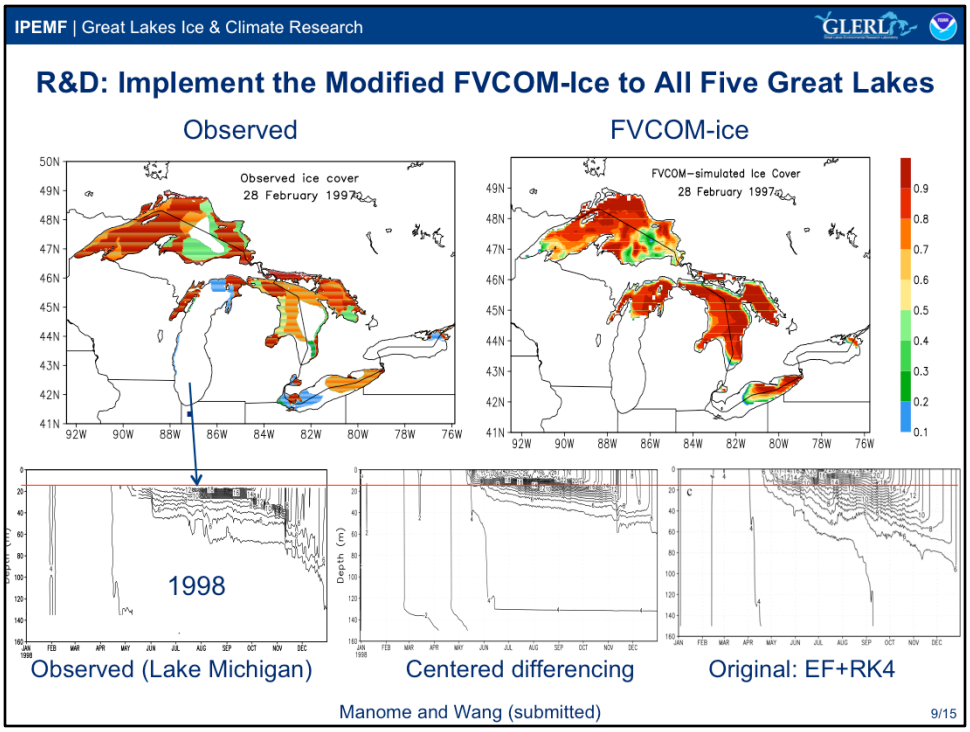
FVCOM – Finite Volume Community Ocean Model
(Joint efforts by GLERL and CILER)



Producing 3D structure of the thermocline

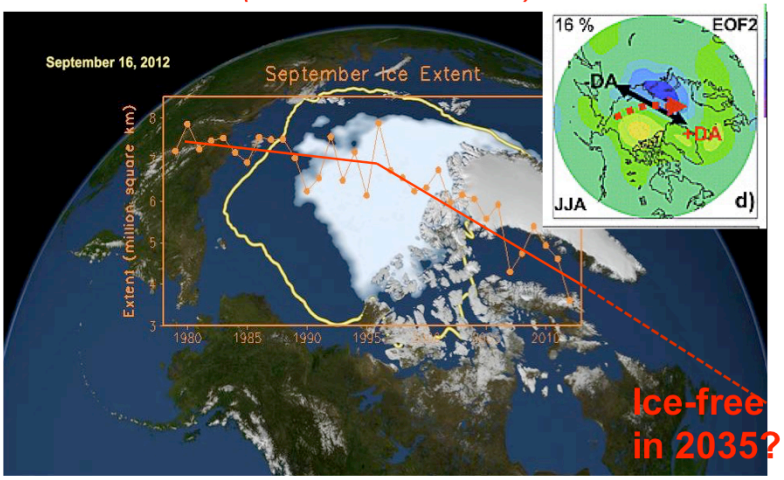
(Transition efforts with ice to NOS/CO-OPS use of FVCOM in coastal ocean and GLCFS/GLOFS with Eric Anderson; potential coupling to ESRL's HRRR, and NCEP's models)

Manome and Wang (submitted): We modified the unstable numerical time integration schemes of Euler forward (EF) and Runge-Kutta order 4 (RK4) in original version to centered differencing scheme, and significantly improve the model simulations.

4) R&D: Arctic Dipole Anomaly (DA) is the major forcing that accelerates Arctic summer sea ice decline

DA is the 2nd EOF mode of Sea Level Pressure Anom. north of 70N

(Collaborated with PMEL)



Wang et al., (2009, 2014).

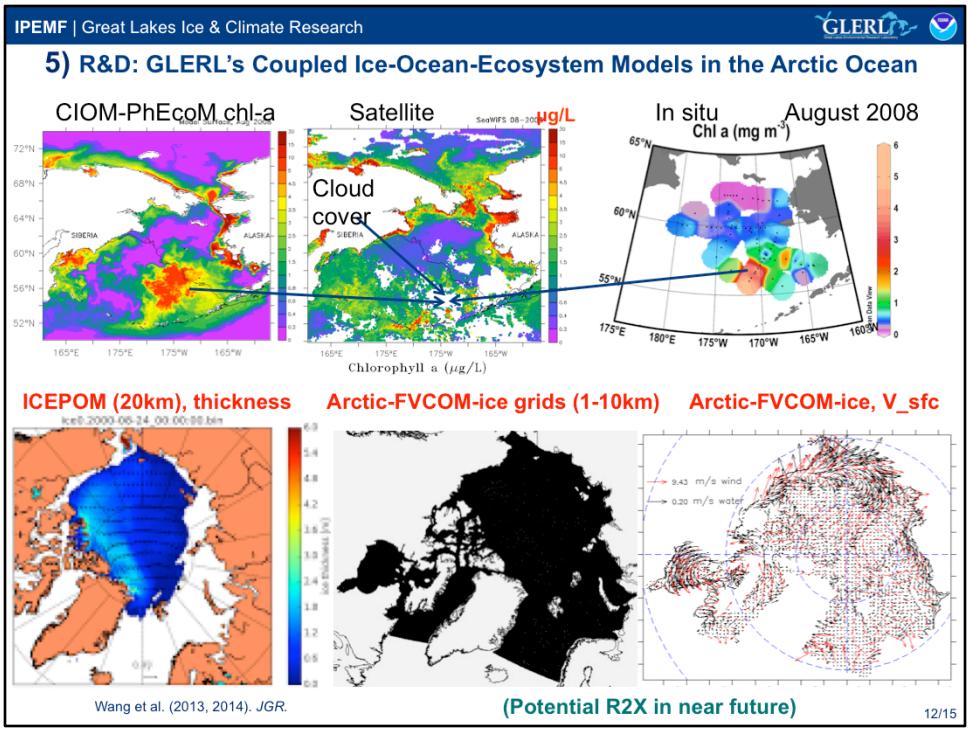
Beyond R&D: Application to walrus, fisheries, whales, Inuit life style and support of new leadership of Arctic Council by U.S. in 2015-2017

Wang et al. (2009) *GRL*, (2014) Chapter Book,

**Highlight the economic impact

Arctic sea routes
Northeast passage (NEP)
Northern Sea Route (NSR)
Northwest passage (NWP)

Exact definition of the Northern Sea Route is the route between the Kara Gate and the Bering Strait under the NSR Administration Agency.



Joint efforts by GLERL, CILER, PMEL, academia

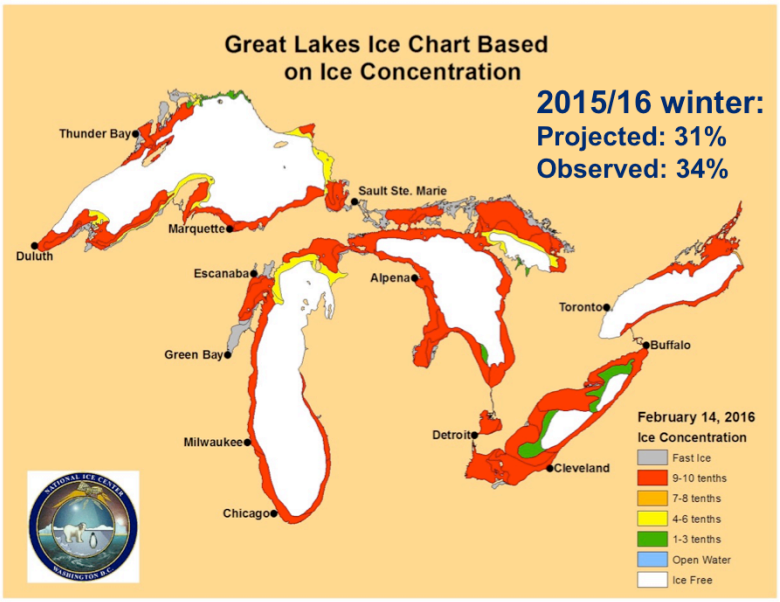
Summary

- **Research revealed the relationships between Great Lakes ice cover and 4 major teleconnection patterns, and led to development of statistical regression models, providing seasonal projection of lake ice using indices of NAO, ENSO, AMO and PDO**
- Great Lakes Ice-circulation Model (GLIM) (POM-based) was developed for studying interactions between water and ice (heat flux, energy transport), which was transferred to short-term ice forecasting in GLCFS
- **5-lake FVCOM-ice model was implemented and refined to the entire Great Lakes for investigate seasonal and interannual variability, which will be transferred to nowcast/ forecast system for NOS, and seasonal projection of lake ice cover at GLERL**
- Arctic teleconnection patterns, DA and AO, are the major forcing to the Arctic sea ice, while AO is also the major forcing to the Great Lakes ice cover. The Northern Sea Route opening and closing are more closely correlated with DA than AO
- **Develop Coupled Ice-Ocean Model (CIOM) and coupled (ice-ocean) Physical-Ecosystem Model (PhEcoM) in the Bering-Beaufort-Chukchi Seas and the Arctic Ocean for application and prediction in the near future**

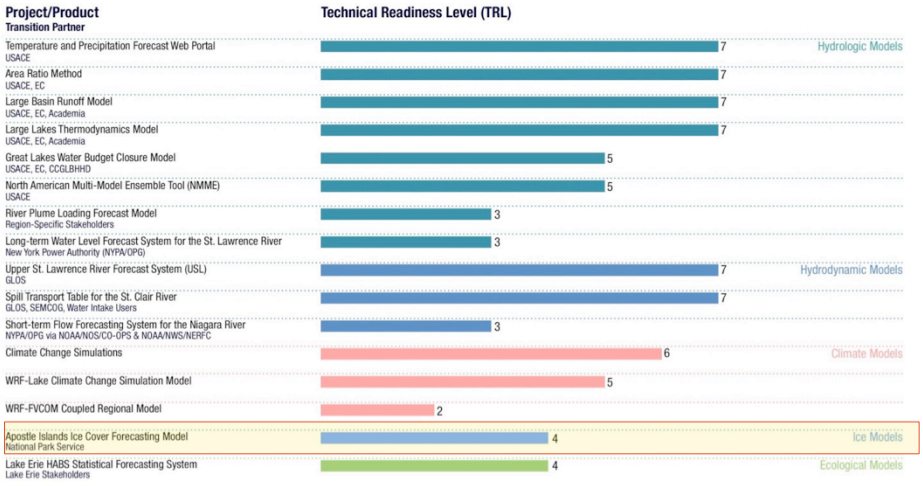
Future Efforts

- Continue to update the climate ice database for research and applications by the Great Lakes community, and to provide seasonal forecast of lake ice
- Run GL-FVCOM-Ice from 1993-present and validate the model using observation data
- Seasonal forecast/projection of lake ice using GL-FVCOM-Ice
- Transition of GL-FVCOM-Ice to NOS/CO-OPS for short-term operational prediction (with Anderson)
- Coupled GL-FVCOM-Ice with GL-WRF (with Lofgren)
- Implement FVCOM-Ice to the Arctic Ocean (with CILER)

Questions?


Great Lakes Ice Chart Based on Ice Concentration
2015/16 winter:
Projected: 31%
Observed: 34%
Thunder Bay
Duluth
Marquette
Sault Ste. Marie
Escanaba
Alpena
Green Bay
Toronto
Buffalo
Milwaukee
Detroit
Cleveland
Chicago
February 14, 2016
Ice Concentration
Fast Ice
9-10 tenths
7-8 tenths
4-6 tenths
1-3 tenths
Open Water
Ice Free

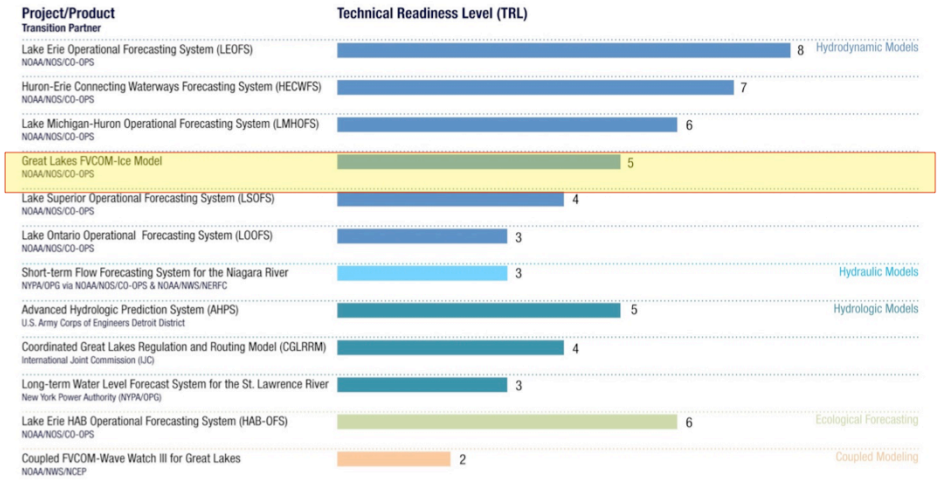
Technical readiness level of IPEMF research to application (R2A) products



Seasonal Regression Forecast Model for all Great Lakes Ice Cover: 7

Additional Information

Technical readiness level of IPEMF research to operation (R2O) products



Additional Information